Method for triggering a thermostat

The invention relates to a method for triggering a thermostat, in particular in a cooling system of a motor vehicle.

A cooling arrangement, which forms this generic type, and a method for operating the cooling arrangement, which forms this generic type, are known from DE 44 09 547. This cooling arrangement can be used to set two different coolant temperatures as a function of specific operating parameters of the vehicle. The influencing operating parameters in this case are the vehicle speed, the load state of the internal combustion engine, and the intake air temperature. As a function of the abovementioned parameters, a control algorithm is used to decide which temperature level the coolant should be set to. In this case, the thermostat in the cooling circuit is triggered by a controller in which the control algorithm is implemented. The temperature levels provided are 90°Celsius and 110°Celsius.

The abovementioned two-point closed-loop control systems tend to oscillate. This problem always occurs when the influencing variables and their values are in a value range in which the control algorithm is set to the respectively other temperature level when there is an extremely small change in the influencing variables. In addition, methods which are already known do not take into account the external temperature, that is to say the ambient temperature, even though the ambient temperatures may fluctuate greatly and have a great effect on the engine temperature and the possible cooling power of the cooling system in extreme weather conditions.

The problem of oscillation has already been identified in EP 0 744 538 A2. The solution proposed is adaptive closed-loop control. The proposal made is that of evaluating the system response to a jump function and using this to adapt the control parameters in an adaptive fashion.

The object of the invention is therefore to specify a method for triggering a thermostat, which method does not tend to oscillate and also takes into account the ambient temperature.

The object is achieved by the features of Claim 1. Advantageous embodiments of the invention can be found in the subclaims and in the description of the exemplary embodiments.

The solution is achieved mainly by pulse-width triggering for the operating elements on the valves of the thermostat being subjected to closed-loop control in an adaptive manner. The aim is to reach the required temperature level in the coolant circuit as quickly as possible initially by predetermined and stored basic adaptation, taking into account the current ambient temperature. Depending on the load state and ambient conditions, three different temperature levels are provided as desired variables for setting the coolant temperature. Once the currently required coolant temperature is reached for the first time after starting, closed-loop control is changed over to fine adaptation. The coolant temperature which is currently to be set is kept as constant as possible by fine adaptation as a function of the desired temperature and the external temperature. If the desired temperature of the coolant, which temperature is to be achieved by closed-loop control, changes on account of a change in the load state of the engine, the newly required

temperature level is set by fine adaptation. This has the advantage that, when the motor vehicle is started, the coolant temperature which is currently to be set can be achieved immediately by the basic adaptation
5   settings.

Fine adaptation is used for adjustment purposes if the coolant temperature set by basic adaptation deviates from the desired temperature. The settings obtained by
10 fine adaptation are, in this case, stored at regular intervals of, for example, 100 seconds, and the basic adaptation settings are overwritten by the new settings. In this way, basic adaptation is matched to the currently prevailing ambient conditions and to the
15 driving style of the driver of the motor vehicle. In this case, the new settings are determined separately and stored specifically for each of the three prespecified temperature levels of 80°C, 90°C and 105°Celsius. Basic adaptation therefore respectively
20 comprises settings for the temperature level of 80°C, for the temperature level of 90°C, and for the temperature level of 105°C.

In one advantageous embodiment of the invention, the
25 stored basic adaptation settings are matched to the ambient temperature by means of a correction function. This correction is made whenever the ambient temperature has changed by a prespecified temperature interval of, for example, 8°Celsius and if the motor
30 vehicle has been out of operation for a prespecified minimum time period of, for example, 2 hours. In this case, the correction is made immediately when the vehicle is restarted, even before basic adaptation begins. Basic adaptation therefore already begins with
35 corrected settings when the ambient conditions have changed considerably, for example if the vehicle was turned off overnight, with the result that it is not

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necessary to first find new settings by fine adaptation. This advantage is important when, for example, the motor vehicle has been switched off on a hot day and is operated again on a following, cooler day. In this case, contrary to other adaptive closed-loop control systems, for example in EP 0 744 538 A2 which employs the control parameters used last, in the method according to the invention, basic adaptation begins with the adapted control parameters, so that it is not necessary to first find new control parameters for the new ambient conditions.

A further advantage of preset basic adaptation is given with the use of a motor vehicle in different climate zones. In this case, the cooling arrangement of the vehicle can be matched to the respective climate zone in an optimum manner by basic adaptation which is geared toward the respective climate zone. The daily temperature fluctuations and the variable load conditions of the engine are compensated for by fine adaptation.

In one advantageous embodiment, the method according to the invention has a fallback level such that control of the coolant is taken over by a proportional controller if the two adaptation stages fail.

A further advantage of the method according to the invention is seen in the ability, in contrast to the prior art, to set three different temperature levels for the coolant temperature. This has the advantage that the engine temperature can be matched more effectively both to the ambient conditions and to the load state of the engine.

Exemplary embodiments of the invention are explained below in greater detail with reference to figures, in which:

5   fig. 1   schematically shows a cooling system with the influencing variables which are most important for the invention;

       fig. 2   shows a simplified Matlab-Simulink representation for determining the temperature

10   level to be set; and

       fig. 3   shows a simplified Matlab-Simulink representation of the adaptive closed-loop control system.

15   Figure 1 schematically shows a typical cooling system for a six-cylinder internal combustion engine 1. In addition to the internal combustion engine, a vehicle radiator 2 and a heat exchanger 3 are integrated in the cooling system. The cooling power of the vehicle

20   radiator can be influenced by an electrically driven fan 4. In order to regulate the power of the fan, the electric motor of the fan is subjected to closed-loop control by a control device 5. Cooled coolant is taken from the vehicle radiator by means of the feed line 6

25   and fed to the cooling lines 8 by the coolant pump 7 in order to feed the cooling channels (not illustrated in any detail) for the combustion cylinders 9. The heated coolant is passed from the combustion cylinders 9 to a three-way thermostat 11 via return lines 10. Depending

30   on the position of the valves in the three-way thermostat 11, the coolant passes out of the internal combustion engine and back again into the vehicle radiator via the radiator return 12, or back again into the cooling lines 8 of the internal combustion engine

35   via the radiator short-circuit 13 and the coolant pump 7.

Depending on the position of the valves in the three-way thermostat 11, the cooling system may be operated here, in a manner known per se, in the short-circuit operating mode, in the mixed operating mode or in the large cooling circuit. The heat exchanger 3 is connected to the high-temperature branch of the cooling system in the internal combustion engine via a temperature-controlled shut-off valve 14. The throughput through the heat exchanger after the shut-off valve 14 is opened can be regulated with an additional electric coolant pump 15 and a pulsed shut-off valve 16 in order to regulate the heating power.

The operating elements on the valves of the three-way thermostat 11 are triggered here by the control device 5. The control device contains a logic component, Logic, in the form of a microelectronic computer unit. The control device is preferably formed by the controller of the engine electronics system. The control algorithms which are outlined in figures 2 and 3 are implemented in the logic component in the form of software programs. In this case, the most important operating data for adaptation of the control parameters are: the actual coolant temperature, the desired coolant temperature, the external air temperature, the PWM pulse duty factor for triggering the valves, and a fault detection means, Failsafe, for activating a fallback level when the closed-loop control system fails.

Fig. 2 shows a simplified Matlab-Simulink representation of the software architecture and the signal flowchart for determining, according to the invention, the coolant temperature to be set. The input signals comprising the intake air temperature 21, mass air flow 22, classification 23 of the driver type, engine speed 24, fuel injection quantity 25 and

external air temperature 26 are further processed with a five-stage decision cascade, and the desired coolant temperature 27 which is matched to the current operating parameters is determined from this. Each stage of the decision cascade is composed of an EDP program for deciding on and calculating a desired temperature as a function of the program input variables. The individual software programs are referred to below as modules.

Here, in engines with port injection, the five-stage decision cascade is composed of the modules KE_ECT (for KanalEinspritzer [port injector] Engine Cooling Temperature), ECT_FTK (for Engine Cooling Temperature according to Fahrertypklassifizierung [classification of driver type]), ECT_AT (for Engine Cooling Temperature according to Ansauglufttemperatur [intake air temperature]), ECT_VehSpd (for Engine Cooling Temperature according to Vehicle Speed) and the module ECT_ExtAir (for Engine Cooling Temperature according to External Air Temperature).

In engines with direct injection, the quantity of fuel is determined from the injection quantity. In these engines, the module DE_ECT (for Direkt Einspritzung [direct injection] Engine Cooling Temperature) is used instead of the module KE_ECT for calculating a first desired coolant temperature TMSoll1. The control algorithm contains both modules, for the port injector as well as for the direct injector, as standard. Which module is used is set on an engine-specific basis by activating one of the two modules by means of a program. This choice is represented in the signal flowchart according to fig. 2 by the switching element 28. This procedure has the advantage that only one control algorithm has to be implemented for the various

types of mixture formation, and said algorithm can then be set to the respective engine version.

The first desired coolant temperature TMSoll1 which is calculated from the fuel input is load dependent, that is to say is set to 105°Celsius or to 80°Celsius as a function of the engine speed EngSpd and the quantity of fuel. The first desired coolant temperature TMSoll1 is weighted using the following module ECT_FTK as a function of the current classification FTK of the driver type from the engine controller and either a coolant temperature of 105°Celsius or of 80°Celsius is selected in accordance with the classification of the driver type. The coolant temperature of 80°Celsius is weighted more heavily, i.e. is selected with preference, for classification of the driver type as sporty. The result of this weighting is a second desired coolant temperature TMSoll2.

After the classification of the driver type, the intake air temperature is taken into account in the next stage of the decision cascade. This is done in the module ECT_AT. Detection of the intake air temperature serves to identify a traffic jam. If the motor vehicle is stuck in a traffic jam, it is desirable to lower the desired coolant temperature to 80°Celsius or 90°Celsius, which is triggered by this traffic jam. This is done by lowering the coolant temperature to one of the two abovementioned values if the intake air temperature exceeds a reference value from the temperature interval 40°Celsius to 50°Celsius. The result, after taking into account the intake air temperature, is the desired coolant temperature TMSoll3.

This desired coolant temperature TMSoll3 which is determined is evaluated in the decision cascade by

means of the next module ECT_VehSpd using the current vehicle speed. If the vehicle speed exceeds a first reference value, for example 120 km/h, the coolant temperature is set to 90°Celsius, and if the vehicle speed exceeds a second reference value, for example 160 km/h, the desired coolant temperature is set to 80°Celsius.

In the last stage of the decision cascade, the desired coolant temperature TMSoll4 which is evaluated according to the vehicle speed is evaluated and determined using the external air temperature. In this way, the previously obtained desired coolant temperatures can ultimately be overridden in extreme environmental conditions, for example extreme cold, and a desired coolant temperature TMSoll5 which is to be ultimately applied can be determined, said desired coolant temperature TMSoll5 being predefined as a desired variable for the triggering means of the fan 4 and the three-way thermostat 11. If the external temperature exceeds a first reference value of, for example, 12°Celsius, the temperature is not lowered by the last stage of the decision cascade. The desired coolant temperature is adapted to the external temperature when the temperature falls below the first reference value, of for example 12°Celsius, to a desired coolant temperature of 90°Celsius. If the external temperature drops further and if it falls below a second reference value, of for example minus 15°Celsius, the desired coolant temperature is set to 105°Celsius independently of the other influencing variables.

The desired coolant temperature TMSoll5 which is ultimately present after the fifth stage is retained as a desired variable for the adaptive closed-loop control system according to fig. 3 for a minimum time period,

of for example 100 seconds, independently of the input signals 21, 22, 23, 24, 25, 26 and of the vehicle speed. This hold function can be realized, for example, with a holding element or a program waiting loop. In the signal flowchart in figure 2, the hold function of the desired coolant temperature which is determined is symbolized by a timing holding element 29.

The desired coolant temperature which is determined by the decision cascade according to fig. 2 is finally further processed by the adaptive open-loop and closed-loop control systems, as outlined in greater detail in fig. 3. The input end of the open-loop control system is provided with signal values for the desired coolant temperature TMSoll, for the actual coolant temperature TMIst, for the external air temperature, for the basic adaptation open-loop and closed-loop control parameters which are to be read in, GA Parameters, for the activation of basic adaptation, Activation GA, for the activation of fine adaptation, Activation FA, and for the activation of the fallback level, Failsafe, if the open-loop control system operates incorrectly or fails because, for example, one of the input signals is no longer available. In figure 3, the signal input is symbolically represented by the connection pins 31, 32, 33, 34, 35, 36 and 37 and denoted with the corresponding signal value.

The triggering means for the thermostat 11 comprises the software module 40 for basic adaptation, the software module 41 for fine adaptation, the software module 42 for pilot control of the operating elements on the valves of the three-way thermostat 11, and a digital proportional controller 43 which may also be in the form of a software module.

Basic adaptation is activated when the control device 5 is connected to the voltage of the vehicle electrical system when the vehicle is started and the desired coolant temperature is less than 90°Celsius. The

5 desired coolant temperature is used as a decision criterion for activation of basic adaptation so that a check by a (German) technical supervisory body of the exhaust gas limit values is not impeded. To be precise, engine temperatures of 105°Celsius, which are optimal

10 for exhaust gas levels, are used for the statutorily prescribed exhaust gas test, so that basic adaptation cannot be used for setting a desired temperature, which is determined in accordance with the algorithm from fig. 2, of below 105°Celsius. In other words, the

15 three-way thermostat 11 is not triggered by basic adaptation during the exhaust gas test. In addition, basic adaptation must be active only during operation of the engine. If basic adaptation were active when the engine is at a standstill, for example, this would

20 corrupt the adaptation values in the form of basic adaptation values GA_Parameters on the terminal 34 in the case of self-adaptation of basic adaptation at the predominantly prevailing ambient climatic conditions.

25 A self-reset function of the GA_Parameters may be performed, for example, by the submodule GA_Reset from figure 4. This submodule is integrated in the software module 40 for basic adaptation. The control deviation between the actual coolant temperature and the desired

30 coolant temperature is also registered and integrated in this submodule. If the integral exceeds a specific value, basic adaptation is reset and the original control parameters are replaced by new control parameters which, for example, are calculated from the

35 integrated temperature deviation and the temperature characteristic diagram of the pilot control means for triggering the thermostat. At the start of the

integral, the actual temperature has to be within the range of the proportional controller 43 once. The reset is used to improve the control parameters of basic adaptation when they are very poor. The reset also
5   matches basic adaptation to different ambient climatic conditions.

The correction factor TMGACorr for varying the controller parameters of basic adaptation is obtained,
10   for example, from the mean integrated temperature Tmean of the respective desired temperature TMSoll of 80°Celsius or 90°Celsius and the characteristic variable of the pulse-width control TMGAGrad for the change in the cooling water temperature as a function
15   of the pulse duty factor of the pulse-width control in accordance with the following equation:

TMGACorr = (Tmean-TMSoll)*TMGAGrad

20   where TMGAGrad is measured in %/°C. A typical value for a pulse-width control used was a 3% increase in the pulse duty factor for a 1° temperature decrease in the coolant circuit. The desired temperature values which are determined in accordance with the algorithm from
25   fig. 2 can be used for TMSoll. The correction determined in this way is still a function of the ·ambient temperature.

The dependence of the settings on the ambient
30   temperature is taken into account by a further correction function which is integrated in the software module 40 for basic adaptation. To this end, the external air temperature is read in at PIN 33 as a digital value. The effect of the external air
35   temperature on the cooling power of the cooling system is taken into account by a correction characteristic diagram and a pulse duty factor of the pulse-width

control is accordingly selected, this pulse duty factor compensating for the effect of the external temperature. This compensation may involve, for example, taking into account the effect of the external temperature as a multiplicative correction factor for changing the cooling water temperature as a function of the pulse duty factor TMGAGrad. The correction factor can then expediently be found in the abovementioned characteristic diagram as a function of the measured external temperature.

After the controller has been connected to the voltage of the vehicle electrical system, basic adaptation is generally active only once for the following driving cycle. In contrast, fine adaptation 41 (fig. 3) runs permanently and begins after the desired temperature of 80°Celsius or 90°Celsius has been reached for the first time by basic adaptation and basic adaptation has ended. By way of example, a threshold value comparator (not illustrated) can establish when the desired temperature is reached and then transmit a corresponding start signal, Activation FA, to the input pin 36 of the fine adaptation means 41. In contrast to basic adaptation, correction is determined over time in the case of fine adaptation. The number of time components of the total operating period of the current fine adaptation phase in which the actual temperature of the coolant deviates from the desired temperature is then recorded, for example. Furthermore, a correction value TMFACorr is calculated in the fine adaptation means 41, fed back to the basic adaptation means 40 in a control loop and used to correct triggering of the pilot control means 42.

Finally, in the pilot control means 42, the predefined signal TMGA at the output of the basic adaptation means 40, which signal contains the correction information,

is used to determine the correction of the pulse-width pulse duty factor in accordance with the characteristic curves of the operating elements used in the three-way thermostat, and said correction is additively
5   superimposed on the controller output of the proportional controller 43. The superimposition is symbolically represented by reference numeral 45 in fig. 3. The process 30 finally outputs a pulse duty factor of the pulse-width modulation which is used to
10 operate the operating elements in the three-way thermostat.

The closed-loop control system according to figure 3 has the advantage, in particular on account of the
15 adaptive superimposition of basic adaptation and fine adaptation on the output of the proportional controller 43, that an emergency function can be provided in a very simple manner. If the basic adaptation means or the fine adaptation means is not operating correctly,
20 the two modules can be switched off in a simple manner by a corresponding signal, Failsafe, which is symbolized at terminal 37. The coolant temperature is then set solely by the proportional controller 43.

25 The ambient conditions are taken into account by detecting the external air temperature by means of a corresponding temperature sensor which supplies a temperature signal to the input of the terminal 33. This measured external air temperature is taken into
30 account by the software in the proportional controller 43, by the software in the basic adaptation means 40 and by the software in the fine adaptation means when determining the controller settings and adaptation. Said temperature is taken into account here using a
35 computer by means of temperature characteristic diagrams which take into account the dependence of the cooling power on the external temperature. It is thus

possible to set triggering of the three-way thermostat to the current ambient temperature too. Adaptation can therefore be deactivated particularly in the case of high external temperatures which may possibly prevent a

5   desired coolant temperature of 80°Celsius being reached, since adaptation would be nonsensical in the case of impossible predefined desired values.